

**UNITED STATES AIR FORCE
ARMSTRONG LABORATORY**

**Desktop Corrosion Control Study for
Eagle Meadows Military Family
Housing Annex at Dover Air Force
Base, Delaware**

David M. Mihalick, Second Lieutenant, USAF, BSC

May 1997

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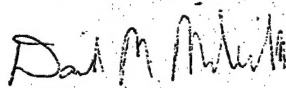
Occupational and Environmental Health
Directorate
Bioenvironmental Engineering Division
2402 E Drive
Brooks AFB, TX 78235-5114

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DAVID M. MIHALICK, Lt, USAF, BSC
Consultant, Water Quality Branch



JAMES D. MONTGOMERY, Lt Col, USAF, BSC
Chief, Bioenvironmental Engineering Division

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DESKTOP CORROSION CONTROL STUDY FOR EAGLE MEADOWS MILITARY FAMILY HOUSING ANNEX AT DOVER AIR FORCE BASE, DELAWARE

INTRODUCTION

Dover Air Force Base (AFB) is located 3 miles southeast of the city of Dover, Delaware. The base is part of Air Mobility Command (AMC) and is home to the 436th Airlift Wing, which operates the Lockheed C-5 Galaxy. There are two water systems in place at Dover AFB, one serving the main base and one serving the Eagle Meadows Military Family Housing Annex. There are no problems reported with the system serving the main base. The system serving the Eagle Meadows Military Family Housing Annex (Potable Water System DAFB 474) exceeds the action level for lead established by the Environmental Protection Agency (EPA) in the Lead and Copper Rule. Consequently, the base must conduct a Desktop Study to identify optimal corrosion control treatment.

The Lead and Copper Rule (LCR) went into effect on 7 June 1991. All community water systems and non-transient non-community water systems are subject to the provisions of the rule. The Eagle Meadows Military Family Housing Water System (System #474) is a community water system. Furthermore, the LCR divides water systems into small, medium, and large systems, depending on how many people the system serves. A small system is one serving less than 3,300 people. System #474 serves a population of approximately 1,050 and is classified as a small system. The LCR requires that lead and copper levels in drinking water be below a certain action level (AL). If the lead or copper concentration exceeds the respective action level, then a series of steps must be taken to bring the system back in compliance. The action level for lead is set at 0.015 mg/L, while the action level for copper is 1.3 mg/L.

Actions that must be taken include implementation of a public awareness and education program, corrosion control treatment, source water treatment, and lead service line replacement. The EPA has a package of public education materials that should be distributed to consumers when a system is out of compliance. The EPA package is a minimum requirement, and the system may supplement this information with location specific information. Some of the required actions are not applicable for all water systems. For example, if the source water does not have detectable concentrations of lead or copper, then source water treatment is not necessary. Additionally, as is the case with system #474, if the system has no lead service lines, then no lead service line replacement program is required.

Under the LCR, water samples are taken from taps served by the distribution system. If greater than 10 percent of the water samples exceed either the lead or copper action level, then corrective action must be initiated. Action Levels are not the same thing as Maximum Contaminant Levels (MCLs) established in the Safe Drinking Water Act. Maximum Contaminant Levels govern the acceptability of individual samples. There is no MCL for lead or copper, only the action levels.

The scope of this project was to complete a Desktop corrosion control study for the Eagle Meadows Military Family Housing Annex water distribution system at Dover AFB. The goal of the project was to determine, if possible, the cause of high lead in first draw tap sampling under the LCR, and to recommend optimal corrosion control treatment. The Environmental Protection Agency outlines a seven step approach for completing desktop evaluations (LCR Guidance Manual 1992). The seven steps to follow, as presented in the LCR Guidance Manual, are listed below.

1. Define existing conditions
2. Monitor Lead and Copper at points of entry and determine source water treatment needs
3. Define constraints
4. Identify corrosion control priorities
5. Eliminate unsuitable approaches
6. Evaluate viable alternatives
7. Evaluate each alternative based on four selection criteria
 - a. performance
 - b. feasibility
 - c. reliability
 - d. cost

All data used in completing this study were gathered by personnel at Dover AFB. Major Ronald Marchioni and TSgt Deral Freysinger were the main points of contact at the base and collected most of the information. Lt David Mihalick reviewed lead and copper sampling results and all other provided information. Appendix A is a summary of the lead and copper sampling results. Other reference information was obtained from the EPA, from The New England Water Works Association (NEWWA), and from various research articles. The table below provides a list of contacts:

Table 1. List Of Contacts

Name	Organization	Phone Number
Major Ronald Marchioni	Bioenvironmental Engineering 436 AMDS/SGPB	DSN 445-2595 (302) 677-2595
TSgt Deral Freysinger	Bioenvironmental Engineering 436 AMDS/SGPB	DSN 445-2595 (302) 677-2595
Chad Hall	State of Delaware	(302) 739-5410 FAX 3839
Karen Eager	NEWWA	(603) 298-7061

The remainder of this consultative letter highlights corrosion control background information and steps through the EPA approach for performing desktop corrosion control studies. After evaluation of the seven steps, one of three general treatment options will be chosen as optimal corrosion control treatment (unless optimal conditions already exist, in which case no further action is required). The three general corrosion control treatment techniques recognized by the EPA are pH/Alkalinity adjustment, calcium carbonate precipitation, and introduction of corrosion inhibitors (phosphates or silicates).

CORROSION CONTROL BACKGROUND

Corrosion of water distribution systems is a common problem throughout the United States. Because every water system is unique there are no automatic or easy answers to corrosion problems. Sources of lead in water first draw tap samples come from various sources. The first 100 mL of a first draw sample represents water that was stagnant in the faucet. Because many faucets are brass, and because brass contains a significant percentage of lead, the first 100 mL may contain elevated lead levels. The next 400-500 mL of sample represents water that was in the pipes most closest to the tap. Generally, there are many lead/tin soldered joints close to the tap. Lee, *et al.*, concluded that "lead-based solder is the most significant source of lead at the tap" (1989). Consequently, this portion of a first draw sample will potentially contain high lead levels. Other sources of lead and copper in water distribution systems include service lines, lead goosenecks, water meters, and valves. Additionally, many water wells contain lead packers between the casing and screen. The packers, coupled with lead plugs can contribute to lead in potable water supplies (American Water Works Association Research Foundation 1990).

Of the three common corrosion control treatment techniques, pH adjustment is probably the most common. Adjusting the pH or alkalinity of the water in the distribution system is known as a passivation mechanism. The goal of passivation is to form metal complexes at the pipe surface that are less soluble than complexes that would form otherwise. The intent of pH/Alkalinity adjustment is "to induce the formation of less soluble compounds with the targeted pipe material" (LCR Guidance Manual 1992). Generally, water with high pH and low alkalinity is the least soluble to lead and copper.

Introduction of corrosion inhibitors is another passivation technique. Commonly used inhibitors are phosphates and silicates. Corrosion inhibitors are added directly to the water supply and form complexes at the pipe surface that are less soluble than lead and copper. These complexes create a protective layer. Generally, the action of phosphate inhibitors is better understood and their use is more common than silicate inhibitors (Medlar and Kim 1994).

Calcium carbonate precipitation is sometimes a useful treatment technique. The idea is to precipitate calcium carbonate from the water in hopes of forming a protective layer on the pipes' interior surface. Ideally, the precipitated protective layer is thin and uniform so as not to restrict flow. Several indices exist which are intended to help predict the likelihood of precipitating calcium carbonate. The EPA recommends using the Calcium Carbonate Precipitation Potential (CCPP) in *The Lead and Copper Rule Guidance Manual: Volume II*. It is very difficult to

accurately predict the formation of a calcium carbonate layer throughout the distribution system. Calcium must be available at all points to ensure the entire system is covered. This is analogous to the need to maintain a chlorine residual in the distribution system. In order for disinfection to be effective, chlorine must be present at all points in the system. Likewise, in order to precipitate a protective layer of calcium carbonate, calcium must be present throughout the system. Furthermore, it is difficult to ensure that the layer formed is uniform. If the calcium carbonate begins to build up in spots, the flow will be restricted and pressure problems may develop.

The most appropriate corrosion control mechanism varies with water quality parameters and the distribution system characteristics. The seven step approach guides a water system toward the optimal treatment technique for its system.

EPA SEVEN STEP APPROACH

Define Existing Conditions

The Eagle Meadows Military Family Housing Annex water system exceeds the EPA action level in the 90th percentile sample for lead. The 90th percentile sample for System #474 is 0.021 mg/l, which is above the action level of 0.015 mg/l (see sample results in Appendix A). The system draws water from two wells. Well #1 is used to satisfy daily demand, and Well #2 is used as backup. Well #1 has a 12 month average production of 285.3 gpm (0.41 mgd). Well #2 has a 12 month average production of 19.4 gpm (0.028 mgd).

The distribution system is 95 percent PVC and 5 percent lined cast iron pipe. All interior piping is copper. There are no lead service lines. The system was built in the mid 1970's, so it is likely that the interior piping contains lead soldered joints. No specific information on joints, valves, faucets, etc. was available. Source water is currently disinfected with chlorine gas and treated with sodium fluoride before it enters the distribution system.

Monitor Source Water

The initial concern when lead and copper problems occur is the source water. If the source water contains high levels of lead and/or copper, and the treatment plant does not adequately remove these contaminants, then they will be present in the tap samples. Theoretically, a system with poor source water quality could violate the LCR and have no corrosion problems. Based on available data there are no problems with lead or copper in the source water.

Table 2. Water Quality Parameters ^a

PARAMETER	Well #1	Well #2	Distribution System
Lead (mg/L) ^b	<0.001	<0.001	<0.001
Copper (mg/L) ^b	0.046	0.0875	0.0415
Iron (mg/L)	0.045	0.578	<0.030
Manganese(mg/L)	<0.030	.0015	<0.030
pH	7.5	7.5	7.5
Alkalinity (mg/L)	267	268	266
Calcium (mg/L)	16.99	15.88	17.05
Specific Conductance ()	488.5	472.5	488
Temperature (degrees C)	16	16	16
Orthophosphate	<0.10	<0.10	<0.10
Silica	19.5	18.5	30.5
Langelier Index ^c	-0.72	-0.75	-0.72
CCPP ^c	-21.25	-21.56	-21.22

^a Values shown are average values from two separate sampling events.

^b See Appendix A for complete lead and copper tap sampling results.

^c Calculated using RTW Model (see Appendix C)

Define Constraints

Realistic constraint definition is vital to a successful corrosion control program. A solution might appear effective when evaluated for its ability to eliminate lead and copper in first draw tap water; however, when evaluated considering its effect on other water quality goals, the distribution system, or wastewater considerations, the solution might prove ineffective. Tables 3-3a and 3-3b of the LCR Guidance Manual address possible constraints (Appendix B).

Table 3-3a indicates that pH adjustment before disinfection will reduce chlorine effectiveness. The minimum CT (concentration multiplied by contact time) value must be maintained after the pH is elevated. This may require increasing the free chlorine residual or the contact time. Otherwise, there is an increased potential for violation of the Coliform Rule with pH adjustment. If sodium based chemicals are used to alter pH/alkalinity, the effect on total sodium in the finished water should be considered. Sodium is already added to the Eagle Meadows water system in the form of sodium fluoride. The optimal place for the pH adjustment is somewhere after chlorination, as close to entry into the distribution system as conditions permit.

If high levels of dissolved metals exist, raising the pH could precipitate these metals. If the metals precipitate, the particulates can cause scaling of the plumbing, clogging of heat exchangers, or unacceptably high turbidity. If the water contains high levels of calcium or dissolved inorganic carbon (DIC), unintentional precipitation of calcium carbonate may result. DIC in excess of 15 mg/L can lead to an increase in lead and copper by forming soluble metal

complexes (Medlar and Kim 1994). The metals concentrations reported in Table 2 above are relatively low.

Table 3-3b indicates that phosphate based inhibitors can have detrimental effects on the water system. First, phosphate based inhibitors tend to deplete chlorine residuals throughout the distribution system. This affects the disinfection capacity. If this is a problem, additional chlorine can be added to satisfy the increased chlorine demand created by introduction of the phosphates. Second, some systems have experienced an increase in microbial growth after introduction of phosphate based inhibitors, resulting in unwanted biofilms. If corrosion byproducts are released after the inhibitors are introduced, coliforms may be detected with greater frequency. Finally, some inhibitors, like zinc orthophosphate, must be carefully considered because of the contaminants they can add to the wastewater. Use of zinc orthophosphate can increase zinc concentrations in WWTP effluent or in processed sludge. The housing annex discharges wastewater to a local WWTP. It contributes a relatively small volume of water to the WWTP and additives should not significantly effect the overall quality of the wastewater going to the plant. Any final decisions must consider limitations in the WWTP National Pollutant Discharge Elimination System (NPDES) permit or other applicable regulations.

In addition to the above process constraints, a myriad of functional constraints exist. Addition of any chemicals to the system must be carefully controlled. If the chemical additions are manual, the operators will need proper training. If the chemicals are added mechanically, equipment must be purchased and monitored. Also, users with specific water needs, such as health care facilities or heating plants, must be notified of any changes in the treatment process. Finally, inhibitors may cause physical water quality problems. The result can be red water, dirty water, color, and sediment complaints because of the action of the inhibitor on existing corrosion byproducts. Although each technique has certain drawbacks and limitations, they each offer benefits depending on the specific water quality.

Identify Corrosion Control Priorities

There are no problems reported with the source water in the Eagle Meadows Military Family Housing Annex. Source water treatment is not a priority. Also, the copper levels are well below the EPA action level of 1.3 mg/L. The only problem is the high lead levels. Since lead is not a problem in the source water, it must be leaching into the water from the distribution system. The selected corrosion control treatment will focus on control of lead in the housing annex distribution system.

Eliminate Unsuitable Approaches

Calcium Carbonate precipitation does not appear to be a viable solution to the lead problem. The CCPP is easily calculated with the Rothberg, Tamburini & Winsor Model for Corrosion Control and Process Chemistry (RTW Model). The EPA recommends a CCPP of 4-10 mg/L for precipitation to be effective. Currently, the water from Well #1 has a CCPP of -21.25 mg/L and the water from Well #2 has a CCPP of -21.56 mg/L. The water in the distribution system has a

CCPP of -21.22 mg/L (see Appendix C for model results). These large negative values indicate that the water is undersaturated with calcium carbonate. Furthermore, the Langelier Index for the water is around -0.75, which also indicates that the water is undersaturated with Calcium Carbonate. In order to raise the CCPP above 4 mg/L the system would have to add 26 mg/L of pure calcium carbonate (this figure was determined using the RTW model: see Appendix D for results). Adding that much calcium to a moderately hard source water (81 mg/L) is not recommended. The increased hardness might cause scaling problems in water heaters. These facts preclude Calcium Carbonate Precipitation as a viable corrosion control treatment option.

Evaluate Viable Approaches

The first viable approach is pH/alkalinity adjustment. Important parameters to consider with this alternative are pH, alkalinity, TDS, and temperature (LCR Guidance Manual 1992). This technique has proven effective at limiting corrosion from brass and lead/tin solder (Medlar and Kim 1994). The minimum lead and copper solubilities occur at a pH of around 9.8 and a DIC of 30-50 mg CaCO_3 / L (LCR Guidance Manual 1992). The water under consideration has a pH of 7.5 and a DIC concentration of 289 mg CaCO_3 / L (estimated using Table A-2 in Appendix A of reference 3). In order to minimize lead solubility the pH would have to be raised considerably and the DIC would have to be decreased. Raising the pH significantly will likely cause taste problems because the water will be too basic. The system has already experienced complaints due to poor taste and odor. Additionally, raising the pH will increase the potential for the precipitation of dissolved metals. According to Chad Hall, who works in the Office of Drinking Water in the Division of Public Health, many aquifers in the area have water with pH of approximately six. For small systems drawing water from these aquifers, the state often recommends raising the pH by adding lime. Even though minimum solubility occurs at a pH above 9, many systems have solved their problems simply by raising the pH range from 6.0 to 8.0 (Lee, *et al.*, 1989). Since the aquifer supplying the Eagle Meadows system already has a pH of 7.5 raising the pH is not likely to provide the same benefits. While most of the metals levels are relatively low, the iron level in Well #2 is high enough to cause concern. The secondary drinking water standard for iron is 0.30 mg/L. The measured level in Well #2 was an average of 0.578 mg/L. Precipitation of iron can cause colored water problems. Water that is colored will likely result in a loss in consumer confidence.

The final alternative is the addition of corrosion inhibitors. System #474 appears a likely candidate for orthophosphate inhibitors because it has a stable pH. The pH at both sources and in the distribution system is 7.5. Orthophosphates are effective corrosion inhibitors at pH values of 7.4-7.8. Additionally, since the system is well buffered (DIC of 34 mg C / L) the acidic effects of the phosphate inhibitors should be neutralized (LCR Guidance Manual 1992). The use of silicate inhibitors is another possibility, however, the mechanism by which they control corrosion is not clear. The only advantage associated with the use of silicates over phosphates would be the ability of silicate inhibitors to sequester soluble iron, thereby eliminating red and black water events associated with high iron and manganese (Medlar and Kim 1994). This advantage would be more of a consideration, if there were problems with water color. There were none reported. Among the different forms of corrosion control treatment, orthophosphate is one of the most commonly used and best understood techniques.

Recommend Optimal Treatment

After considering the information provided for the preparation of this desktop study, introduction of orthophosphate inhibitor appears to be the optimal corrosion control treatment for Eagle Meadows. The EPA states in the *Corrosion Control Guidance Manual: Volume II* that there are three critical parameters that one must consider when operating an orthophosphate corrosion control treatment program. The three parameters are:

1. maintaining a stable pH in the inhibitor's effective range throughout the distribution system.
2. determining the inhibitor composition best suited for the specific water quality objectives and conditions; and
3. applying the appropriate dosage to accommodate background orthophosphate demand as well as the corrosion control protection sought.

As previously mentioned, the system has a stable pH of 7.5, which is within the optimal range of 7.4-7.8. If the base decides to utilize an orthophosphate system, then the proper inhibitor composition and dose can be determined. There are many companies that manufacture and distribute phosphate inhibitors. The Calgon Corporation estimated preliminarily that it will cost between \$10 and \$20 per day to treat the water at Dover AFB, depending on the type of phosphate inhibitor used. The annual cost of the inhibitor should be around \$5,000. The company contracted to supply the inhibitor will evaluate the situation specifics. The company will set up the feed system and give details on the quantity and price of chemical required to treat the water. Because the water has a high alkalinity, addition of orthophosphate may not reduce lead solubility as much as it would if the water had a low alkalinity. The EPA states that "for waters with high alkalinity, however, orthophosphate dosage provides much greater reduction in lead concentration than is possible with pH and alkalinity adjustment alone" (Control of Lead and Copper in Drinking Water 1993).

Phosphates are available with different amounts of PO_4 and should be evaluated using normalized data. They should be compared based on price per pound of PO_4 rather than price per pound of product (Medlar and Kim 1994). Sodium or potassium phosphate salts have double the PO_4 content of common zinc orthophosphates, and also provide the advantage of not lowering the pH because they are neutral to basic in nature (Medlar and Kim 1994). As mentioned previously, a stable pH is essential to the success of an orthophosphate system. Once the inhibitor is added samples should be taken at the farthest reaches of the distribution system to monitor for adequate inhibitor residual. Generally, large doses are added during the early phases of treatment to help establish the protective barrier and satisfy the background demand. Once the system has stabilized, the dose is reduced to a level that satisfies the background demand and provides a residual at all points in the distribution system. Manganese, Iron, Copper, Aluminum, Zinc, Lead, Calcium, Magnesium, Barium, Radium, Sodium, and Potassium create a phosphate demand (LCR Guidance Manual 1992). Many systems control corrosion problems with an orthophosphate dose of 0.4-0.6 mg PO_4/L (Lee, *et al.*, 1989). The EPA claims that utilities that

have had problems with orthophosphates "almost always use improper control conditions" (Control of Lead and Copper in Drinking Water 1993). "The utilities are usually operating in an incorrect pH range or at an insufficient orthophosphate dosage to maintain an adequate level for keeping lead solubility low in all parts of the distribution system" (Control of Lead and Copper in Drinking Water 1993). Again, pH stability is important.

Costs for implementing the prescribed corrosion control treatment system vary depending on the type of system installed. Adding phosphate inhibitors to small water systems is a relatively cheap alternative. The capital costs vary depending on the availability of existing facilities to house the required equipment. Inhibitor feed systems are available for as little as \$1,000 - \$3,000 (Medlar and Kim 1994). Similar systems have been priced for other Air Force installations at \$1,200. Additional expenses will include safety equipment, installation and piping changes, engineering, and construction. If new facilities are needed to house the equipment, then they will also add to the expense. The various costs should be investigated in detail if the base decides to add the phosphate inhibitors. There are many situation specific variables that will effect the final cost, but information in this report provides a rough estimate.

CONCLUSIONS

Phosphate inhibitors are a commonly used corrosion control treatment technique. They have proven effective under stable pH conditions like those in the Eagle Meadows Family Housing Annex. After evaluating all provided information it appears that addition of orthophosphate inhibitors is the best option for controlling lead in first draw tap samples. Capital expenditures for the first year of phosphate addition should cost approximately \$6,200. Additional expenses will include labor and any site specific construction or consulting services required to get the system operational. Any action that the base decides to take should be coordinated through the State of Delaware Division of Public Health, Office of Drinking Water.

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APPENDIX A

**LEAD AND COPPER SAMPLING
RESULTS**

LEAD AND COPPER RESULTS (3rd ANNUAL)

SYSTEM NUMBER 579

	Lead (mg/l)	Copper (mg/l)
1.	.0004	.015
2.	.003	.049
3.	.003	.082
4.	.003	.084
5.	.003	.089
6.	.005	.109
7.	.005	.117
8.	.005	.118
9.	.006	.124
10.	.007	.164
11.	.007	.174
12.	.008	.186
13.	.008	.187
14.	.009	.226
15.	.010	.230
16.	.010	.232
17.	.011	.257
18.	.012	.266
19.	.012	.386
20.	.012	.441

SYSTEM NUMBER 474

1411	1.	.003	.115
1518	2.	.004	.126
1105	3.	.006	.130
7333	4.	.007	.136
1029	5.	.010	.145
1619	6.	.012	.165
7423	7.	.013	.184
1466	8.	.015	.199
7642	9.	.021	.215
1765	10.	.024	.217



APPENDIX B

**EPA CONSTRAINT TABLE FROM LCR
GUIDANCE MANUAL**

SCREENING OF ALTERNATIVES

Table 3-3a. Constraints Worksheet for pH/Alkalinity or Calcium Adjustment Treatment Alternatives

<p style="text-align: center;"><i>Adjusting pH/Alkalinity and/or calcium for corrosion control typically consists of increasing their levels to generate favorable conditions for lead and copper passivation or calcium carbonate precipitation.</i></p>	
A. National Primary Drinking Water Regulations Constraints	
Rule	Constraint
Surface Water Treatment Rule	<p>Reduces inactivation effectiveness of free chlorine if pH adjusted before disinfection.*</p> <p>Potential for interference with dissolved ozone measurements.</p> <p>May increase turbidity from post-filtration precipitation of lime, aluminum, iron, or manganese.</p>
Groundwater Disinfection	<p>Reduces inactivation effectiveness of free chlorine if pH adjusted before disinfection.*</p> <p>Potential for interference with dissolved ozone measurements.</p>
Disinfection Byproducts	<p>Higher THM concentrations from chlorination if pH adjusted before disinfection.*</p> <p>Reduced effectiveness of some coagulants for precursor removal if pH adjusted before coagulation.*</p>
Coliform Rule	<p>Potential for higher total plate counts, confluent growth, or presence of total coliforms when chlorination is practiced.</p>
Radionuclides	<p>In-plant adjustments may affect removal of radioactive particles if precipitation techniques are used for coagulation or softening.</p> <p>Removal of radionuclides during softening may be linked to the degree of softening. Modifying softening practices to achieve corrosion control could interfere with removals.</p>

SCREENING OF ALTERNATIVES

Table 3-3a. Constraints Worksheet for pH/Alkalinity or Calcium Adjustment Treatment Alternatives (continued)

B. Functional Constraints

Increased potential for post-filter precipitation may give undesirable levels of aluminum, iron, or manganese.

Process optimization is essential. Additional controls, chemical feed equipment, and operator attention may be required.

Multiple entry points will require pH/Alkalinity adjustment at each entry location. Differing water qualities from multiple sources will require adjusting chemical doses to match the source.

The use of sodium-based chemicals for alkalinity or pH adjustments should be evaluated with regard to the total sodium levels acceptable in the finished water.

Users with specific water quality needs, such as health care facilities, should be advised of any changes in treatment.

Excessive calcium carbonate precipitation may produce "white water" problems in portions of the distribution system.

It may be difficult to produce an acceptable coating of calcium carbonate on interior piping for large distribution systems. High CCPP levels may eventually lead to reduced hydraulic capacities in transmission lines near the treatment facility while low CCPP values may not provide adequate corrosion protection in the extremities of the distribution system.

- Unless operating restraints dictate otherwise, the optimum location for pH adjustment is after disinfection and near the entrance to the distribution system. If quicklime is used to adjust pH, for example, it needs to be added prior to filtration so inert material does not accumulate in the clearwell or enter the distribution system.

SCREENING-OF ALTERNATIVES

**Table 3-3b. Constraints Worksheet for
Inhibitor Treatment Alternatives**

<i>Corrosion inhibitors can cause passivation of lead and copper by the interaction of the inhibitor and metal components of the piping system.</i>	
A. National Primary Drinking Water Regulations Constraints	
<u>Rule</u>	<u>Constraint</u>
Surface Water Treatment Rule	The application of phosphate-based inhibitors to systems with existing corrosion byproducts can result in the depletion of disinfectant residuals within the distribution system. Additionally, under certain conditions phosphate-based inhibitors may stimulate biofilms in the distribution system.
Groundwater Disinfection	Same as above.
Disinfection Byproducts	No apparent effects.
Coliform Rule	If corrosion byproducts are released after the application of inhibitors, coliforms may be detected more frequently and confluent growth is more likely.
Radionuclides	No apparent effects.
B. Functional Constraints	
<p>Potential post-filtration precipitation of aluminum.</p> <p>Consumer complaints regarding red water, dirty water, color, and sediment may result from the action of the inhibitor on existing corrosion byproducts within the distribution system.</p> <p>Multiple entry points will require multiple chemical feed systems.</p> <p>The use of sodium-based inhibitors should be evaluated with regard to the total sodium levels acceptable in the finished water.</p> <p>The use of zinc orthophosphate may present problems for wastewater facilities with zinc or phosphorus limits in their NPDES permits.</p> <p>Users with specific water quality needs, such as health care facilities, should be advised of any treatment changes.</p>	

NOTE: If pH adjustment is necessary to produce an effective pH range for the inhibitor, then the constraints in Table 3-3a would also need to be evaluated.

APPENDIX C

**RTW MODEL RESULTS FOR EXISTING
OPERATIONS**

STEP 1: Enter initial water characteristics.

Measured TDS	313	mg/L
Measured temperature	16	deg C
Measured pH	7.5	
Measured alk, as CaCO ₃	267	mg/L
Measured Ca, as CaCO ₃	16.99	mg/L
Measured Cl	6	mg/L
Measured SO ₄	1	mg/L

For CT and TTHM functions enter current:

Treated water pH	
Chlorine residual	mg/L
Chlorine or hypochlorite dose as chlorine equivalent	mg/L

STEP 2: Enter amount of each chemical
to be added (expressed as 100% chemical).
Press Alt+C to select chemicals for this list.

Alum 50% solution	0	mg/L
Carbon dioxide	0	mg/L
Caustic soda	0	mg/L
Chlorine gas	0	mg/L
Hydrochloric acid	0	mg/L
Hydrofluosilicic acid	0	mg/L
Lime (slaked)	0	mg/L
Soda ash	0	mg/L
Sodium bicarbonate	0	mg/L
Ctrl+C to add to list	0	mg/L

STEP 3: Adjust at Step 2 until interim water characteristics meet your criteria.

Theoretical interim water characteristics			Desired	Theoretical interim water characteristics			Desired
Interim alkalinity	267	mg/L	> 40 mg/L	Interim pH	7.50		6.8-9.3
Interim Ca, as CaCO ₃	17	mg/L	> 40 mg/L	Precipitation potential	-21.25	mg/L	4-10 mg/L
Alk/(Cl+SO ₄)	38.1		> 5.0	Langelier index	-0.72		>0

Press PAGE DOWN for additional initial, interim and final water characteristics if desired.

Calculated initial water characteristics

Initial acidity	306	mg/L
Initial Ca sat, as CaCO ₃	89	mg/L
Initial DIC, as CaCO ₃	573	mg/L

Theoretical interim water characteristics

Interim acidity	306	mg/L
Interim Ca sat, as CaCO ₃	89	mg/L
Ryznar index	8.94	
Interim DIC, as CaCO ₃	573	mg/L
Aggressiveness Index	11.16	

CT and TTHM Results

Required chlorine residual to maintain current level of giardia inactivation	N/A	mg/L
Estimated maximum total trihalomethane concentration change from current level	N/A	%

Theoretical final water characteristics
after CaCO₃ precipitation

Final alkalinity	N/A	mg/L
Final Ca	N/A	mg/L
Final acidity	N/A	mg/L
Final pH	N/A	
Final DIC, as CaCO ₃	N/A	mg/L

Press PAGE UP to review measured
initial water characteristics, chemical
addition quantities and additional
interim water characteristics.

The RTW Model

Ver. 3.0

ID: Dover AFB - Well #2

STEP 1: Enter initial water characteristics.

Measured TDS	302.9	mg/L
Measured temperature	16	deg C
Measured pH	7.5	
Measured alk, as CaCO3	268	mg/L
Measured Ca, as CaCO3	15.875	mg/L
Measured Cl	5	mg/L
Measured SO4	3	mg/L

For CT and TTHM functions enter current:

Treated water pH	
Chlorine residual	mg/L
Chlorine or hypochlorite dose as chlorine equivalent	mg/L

STEP 2: Enter amount of each chemical
to be added (expressed as 100% chemical).
Press Alt+C to select chemicals for this list.

Alum 50% solution	0	mg/L
Carbon dioxide	0	mg/L
Caustic soda	0	mg/L
Chlorine gas	0	mg/L
Hydrochloric acid	0	mg/L
Hydrofluosilicic acid	0	mg/L
Lime (slaked)	0	mg/L
Soda ash	0	mg/L
Sodium bicarbonate	0	mg/L
Ctrl+C to add to list	0	mg/L

STEP 3: Adjust at Step 2 until interim water characteristics meet your criteria.

Theoretical interim water characteristics			Desired	Theoretical interim water characteristics			Desired
Interim alkalinity	268	mg/L	> 40 mg/L	Interim pH	7.50		6.8-9.3
Interim Ca, as CaCO3	16	mg/L	> 40 mg/L	Precipitation potential	-21.56	mg/L	4-10 mg/L
Alk/(Cl+SO4)	33.5		> 5.0	Langelier index	-0.75		>0

Press PAGE DOWN for additional initial, interim and final water characteristics if desired.

Calculated initial water characteristics

Initial acidity	307	mg/L
Initial Ca sat, as CaCO3	89	mg/L
Initial DIC, as CaCO3	575	mg/L

Theoretical interim water characteristics

Interim acidity	307	mg/L
Interim Ca sat, as CaCO3	89	mg/L
Ryznar index	8.99	
Interim DIC, as CaCO3	575	mg/L
Aggressiveness Index	11.13	

CT and TTHM Results

Required chlorine residual to maintain current level of giardia inactivation	N/A	mg/L
Estimated maximum total trihalomethane concentration change from current level	N/A	%

Theoretical final water characteristics
after CaCO3 precipitation

Final alkalinity	N/A	mg/L
Final Ca	N/A	mg/L
Final acidity	N/A	mg/L
Final pH	N/A	
Final DIC, as CaCO3	N/A	mg/L

Press PAGE UP to review measured
initial water characteristics, chemical
addition quantities and additional
interim water characteristics.

The RTW Model

Ver. 3.0

ID: Dover AFB - Distribution System Sample (Rhode Island Drive)

STEP 1: Enter initial water characteristics.

Measured TDS	312.8	mg/L
Measured temperature	16	deg C
Measured pH	7.5	
Measured alk, as CaCO3	266	mg/L
Measured Ca, as CaCO3	17.05	mg/L
Measured Cl	0	mg/L
Measured SO4	0	mg/L

For CT and TTHM functions enter current:

Treated water pH	
Chlorine residual	mg/L
Chlorine or hypochlorite dose as chlorine equivalent	mg/L

STEP 2: Enter amount of each chemical
to be added (expressed as 100% chemical).
Press Alt+C to select chemicals for this list.

Alum 50% solution	0	mg/L
Carbon dioxide	0	mg/L
Caustic soda	0	mg/L
Chlorine gas	0	mg/L
Hydrochloric acid	0	mg/L
Hydrofluosilicic acid	0	mg/L
Lime (slaked)	0	mg/L
Soda ash	0	mg/L
Sodium bicarbonate	0	mg/L
Ctrl+C to add to list	0	mg/L

STEP 3: Adjust at Step 2 until interim water characteristics meet your criteria.

Theoretical interim water characteristics			Desired	Theoretical interim water characteristics			Desired
Interim alkalinity	266	mg/L	> 40 mg/L	Interim pH	7.50		6.8-9.3
Interim Ca, as CaCO3	17	mg/L	> 40 mg/L	Precipitation potential	-21.22	mg/L	4-10 mg/L
Alk/(Cl+SO4)	N/A		> 5.0	Langelier index	-0.72		>0

Press PAGE DOWN for additional initial, interim and final water characteristics if desired.

Calculated initial water characteristics

Initial acidity	305	mg/L
Initial Ca sat, as CaCO3	90	mg/L
Initial DIC, as CaCO3	571	mg/L

Theoretical interim water characteristics

Interim acidity	305	mg/L
Interim Ca sat, as CaCO3	90	mg/L
Ryznar index	8.94	
Interim DIC, as CaCO3	571	mg/L
Aggressiveness Index	11.16	

CT and TTHM Results

Required chlorine residual to maintain current level of giardia inactivation	N/A	mg/L
Estimated maximum total trihalomethane concentration change from current level	N/A	%

Theoretical final water characteristics
after CaCO3 precipitation

Final alkalinity	N/A	mg/L
Final Ca	N/A	mg/L
Final acidity	N/A	mg/L
Final pH	N/A	
Final DIC, as CaCO3	N/A	mg/L

Press PAGE UP to review measured
initial water characteristics, chemical
addition quantities and additional
interim water characteristics.

The RTW Model

Ver. 3.0

ID: Dover AFB - Blended source water

Blending Application Package

STEP 1: Enter characteristics for waters to be blended.

Water A

TDS	313	mg/L
Temperature	16	deg C
pH	7.5	
Alkalinity, as CaCO3	267	mg/L
Ca, as CaCO3	16.99	mg/L
Cl	6	mg/L
SO4	1	mg/L

Water B

TDS	302.9	mg/L
Temperature	16	deg C
pH	7.5	
Alkalinity, as CaCO3	268	mg/L
Ca, as CaCO3	15.875	mg/L
Cl	5	mg/L
SO4	3	mg/L

STEP 2: Enter portion of blend that is Water A

% Water A in blend	93.63	%
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Press PAGE DOWN for blended water characteristics and chemical treatment calculations.

Press PAGE UP to review characteristics of waters A & B prior to blending
Initial blended water characteristics.

TDS	312.35663	mg/L
Temperature	16	deg C
pH	7.50	
Alkalinity, as CaCO3	267.0637	mg/L
Ca, as CaCO3	16.9189745	mg/L
Cl	5.9363	mg/L
SO4	1.1274	mg/L
Acidity	306	mg/L
Ca sat, as CaCO3	89	mg/L
DIC, as CaCO3	573	mg/L

STEP 3: Enter amount of each chemical to be added to blended water (expressed as 100% chemical).
Press Ctrl+C to select chemicals for this list.

Alum *18H2O	0	mg/L
Alum 50% solution	0	mg/L
Carbon dioxide	0	mg/L
Caustic soda	0	mg/L
Chlorine gas	0	mg/L
Hydrochloric acid	0	mg/L
Hydrofluosilicic acid	0	mg/L
Lime (slaked)	0	mg/L
Soda ash	0	mg/L
Sodium bicarbonate	0	mg/L

STEP 4: Adjust at Step 3 until interim blended water characteristics meet your criteria.

Theoretical interim characteristics			Desired	Theoretical interim characteristics			Desired
Interim alkalinity	267	mg/L	> 40 mg/L	Interim pH	7.50		6.8-9.3
Interim Ca, as CaCO3	17	mg/L	> 40 mg/L	Precipitation potential	-21.30	mg/L	4-10 mg/L
Alk/(Cl+SO4)	37.8		> 5.0	Langelier index	-0.72		>0

Press PAGE DOWN for additional interim and final blended water characteristics if desired.

Press PAGE UP to review initial blended water characteristics, chemical addition quantities and additional interim blended water characteristics.

Theoretical interim blended water characteristics

Interim acidity	306	mg/L
Interim Ca sat, as CaCO3	89	mg/L
Ryznar index	8.94	
Interim DIC, as CaCO3	573	mg/L
Aggressiveness Index	11.15	

Theoretical final blended water characteristics after CaCO3 precipitation

Final alkalinity	N/A	mg/L
Final Ca	N/A	mg/L
Final acidity	N/A	mg/L
Final pH	N/A	
Final DIC, as CaCO3	N/A	mg/L

APPENDIX D

RTW MODEL RUN FOR CALCIUM REQUIRED TO RAISE CCPP

The RTW Model

Ver. 3.0

ID: Dover AFB - Distribution System Sample (Rhode Island Drive)

STEP 1: Enter initial water characteristics.

Measured TDS	312.8	mg/L
Measured temperature	16	deg C
Measured pH	7.5	
Measured alk, as CaCO3	266	mg/L
Measured Ca, as CaCO3	17.05	mg/L
Measured Cl	0	mg/L
Measured SO4	0	mg/L

For CT and TTHM functions enter current:

Treated water pH	
Chlorine residual	mg/L
Chlorine or hypochlorite dose as chlorine equivalent	mg/L

STEP 2: Enter amount of each chemical
to be added (expressed as 100% chemical).
Press Alt+C to select chemicals for this list.

Alum 50% solution	0	mg/L
Calcium carbonate	26	mg/L
Carbon dioxide	0	mg/L
Caustic soda	0	mg/L
Chlorine gas	0	mg/L
Hydrochloric acid	0	mg/L
Hydrofluosilicic acid	0	mg/L
Lime (slaked)	0	mg/L
Soda ash	0	mg/L
Sodium bicarbonate	0	mg/L

STEP 3: Adjust at Step 2 until interim water characteristics meet your criteria.

Theoretical interim water characteristics			Desired	Theoretical interim water characteristics			Desired
Interim alkalinity	292	mg/L	> 40 mg/L	Interim pH	7.95		6.8-9.3
Interim Ca, as CaCO3	43	mg/L	> 40 mg/L	Precipitation potential	4.78	mg/L	4-10 mg/L
Alk/(Cl+SO4)	N/A		> 5.0	Langelier index	0.17		>0

Press PAGE DOWN for additional initial, interim and final water characteristics if desired.

Calculated initial water characteristics

Initial acidity	305	mg/L
Initial Ca sat, as CaCO3	90	mg/L
Initial DIC, as CaCO3	571	mg/L

Theoretical interim water characteristics

Interim acidity	305	mg/L
Interim Ca sat, as CaCO3	29	mg/L
Ryznar index	7.60	
Interim DIC, as CaCO3	597	mg/L
Aggressiveness Index	12.05	

CT and TTHM Results

Required chlorine residual to maintain current level of giardia inactivation	N/A	mg/L
Estimated maximum total trihalomethane concentration change from current level	N/A	%

Theoretical final water characteristics after CaCO3 precipitation

Final alkalinity	287	mg/L
Final Ca	38	mg/L
Final acidity	305	mg/L
Final pH	7.84	
Final DIC, as CaCO3	592	mg/L

Press PAGE UP to review measured
initial water characteristics, chemical
addition quantities and additional
interim water characteristics.